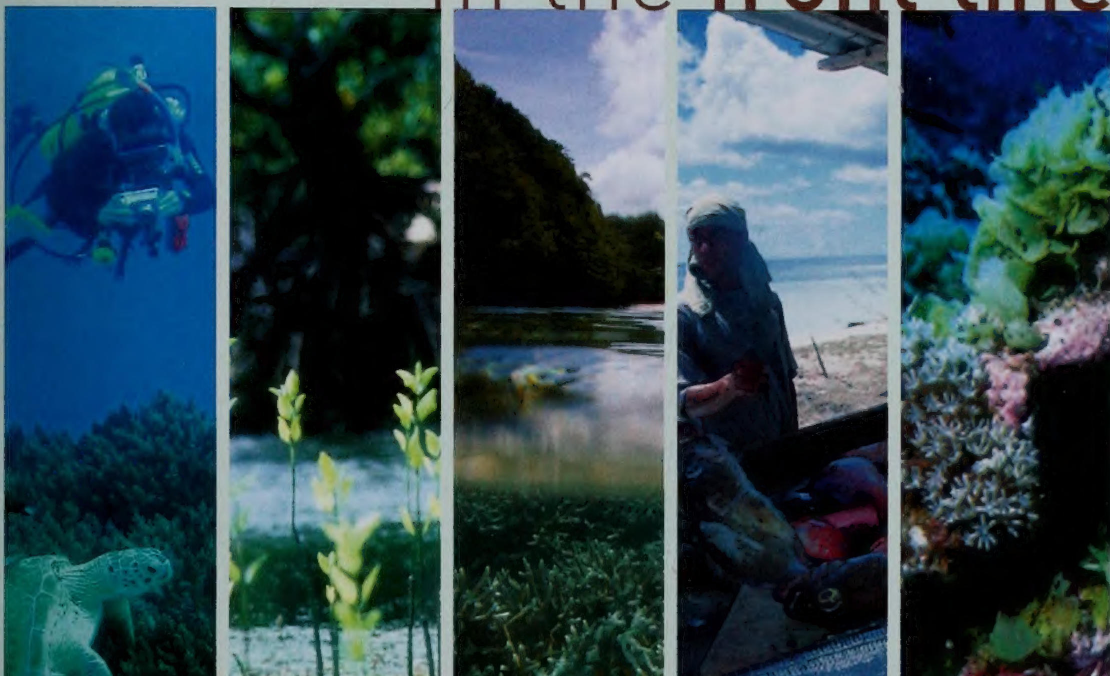
In the front line



Shoreline protection and other ecosystem services from mangroves and coral reefs

UNEP WCMC

ICRAN
International Coral Reef Action Network

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The World Conservation Union

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THE UNITED NATIONS ENVIRONMENT PROGRAMME WORLD CONSERVATION MONITORING CENTRE (UNEP-WCMC) is the biodiversity assessment and policy implementation arm of the United Nations Environment Programme (UNEP), the world's foremost intergovernmental environmental organization. The Centre has been in operation for over 25 years, combining scientific research with practical policy advice.

UNEP-WCMC provides objective, scientifically rigorous products and services to help decision makers recognize the value of biodiversity and apply this knowledge to all that they do. Its core business is managing data about ecosystems and biodiversity, interpreting and analysing that data to provide assessments and policy analysis, and making the results available to national and international decision makers and businesses.

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Contents

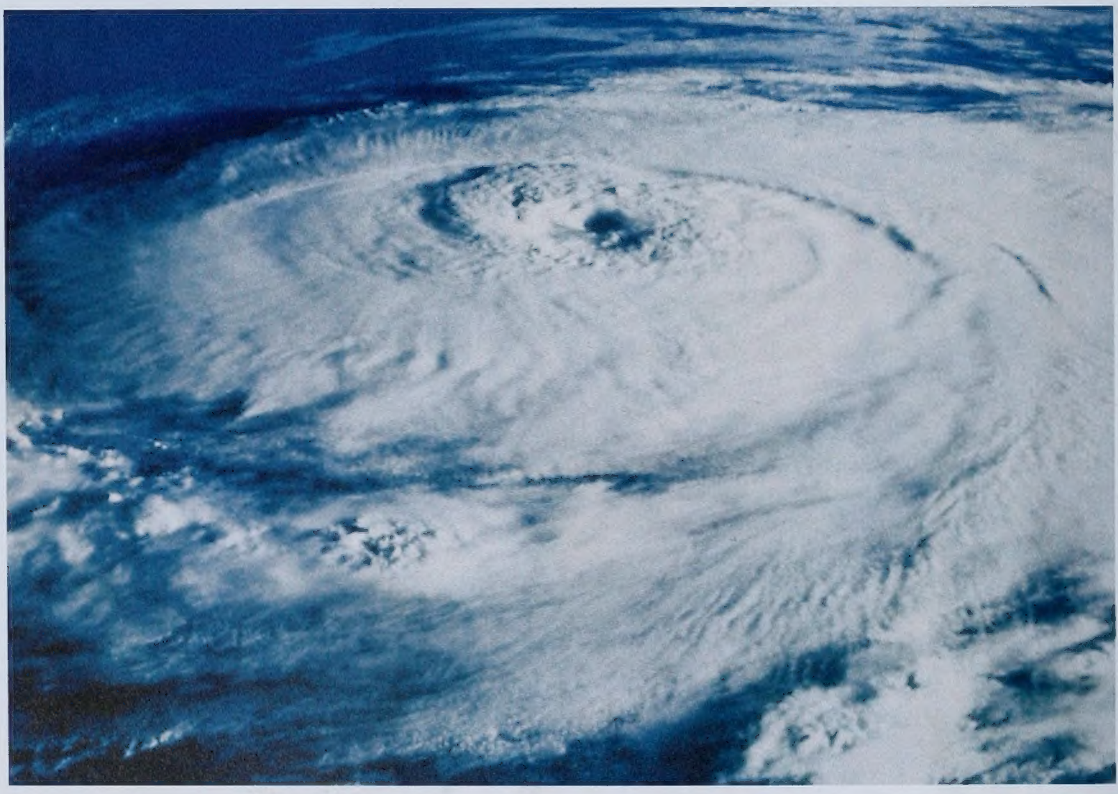
Introduction

The Indian Ocean tsunami of 26 December 2004 and its tragic and devastating consequences were a wake-up call for the global community, dramatically drawing attention to the vulnerability of tropical coastal ecosystems and the dangers of undermining the services they provide to humankind. This was further emphasized by the catastrophic hurricane season in the Gulf of Mexico in 2005 when Hurricanes Katrina, Rita and Wilma caused much publicized and extensive damage to coastal areas. The numerous other tropical storms that affected coastal communities and ecosystems in other parts of the world in the same year received much less attention, but were also notable.

The lessons learnt in terms of loss of life, damage sustained, and approaches to reconstruction and mitigation are critically relevant to future management of the coast in a context of increasing severe weather events such as hurricanes and typhoons, and other potential consequences of global warming. More than ever, it is essential to consider the full value of 'ecosystem services' (the benefits that people obtain from ecosystems) when making decisions about coastal development.

The aim of this publication is to help decision makers and policy makers around the world understand the importance of coastal habitats to humans, using coral reefs and mangroves as an example. It looks at the role of these ecosystems in protecting the coast, and takes into account new studies of this complex topic triggered by the tsunami and tropical storms. The publication also addresses the huge range of other benefits provided by these ecosystems and the role that they can play in coastal development and in restoring and maintaining the livelihoods of those who have suffered from extreme events, whether natural or induced by human activity.

NASA/Still Pictures



Key messages

GLOBAL STATUS OF CORAL REEFS AND MANGROVES

Coral reefs and mangroves are two of the world's rarest ecosystems, covering an area that is an order of magnitude less than that of tropical and subtropical forests. Both ecosystems are under serious threat.

- Some 30 per cent of reefs are already seriously damaged and 60 per cent could be lost by 2030. Threats include overfishing, use of destructive fishing methods, coral mining, pollution, sedimentation, anchor damage and tourism, as well as coral bleaching, disease and tropical storms. This combination of impacts is causing a shift, on many reefs, from a coral-dominated ecosystem to one dominated by algae.
- An estimated 35 per cent of the world's original mangrove cover has already gone, with some countries having lost up to 80 per cent. Mangroves have been degraded by conversion to aquaculture, timber extraction, use of wood for fuel and charcoal production, diseases and storms.

ECOSYSTEM BENEFITS

Coral reefs and mangroves provide benefits under the four categories of ecosystem services defined by the 2005 Millenium Ecosystem Assessment:

- Regulating – e.g. protection of shores from storm surges and waves; prevention of erosion.
- Provisioning – e.g. fisheries, building materials.
- Cultural – e.g. tourism, spiritual appreciation.
- Supporting – e.g. cycling of nutrients, fish nursery habitats.

They are among the most valuable ecosystems in terms of their benefits to humankind:

- Economic valuation of ecosystems needs to be treated with caution but annual values per km^2 have been calculated at US$100 000-600 000 for reefs and US$200 000-900 000 for mangroves.
- The small total area of coral reefs and mangroves belies their importance in terms of fisheries, other extractive uses, shoreline protection and, in the case of reefs, tourism and recreation.
- Both ecosystems contribute significantly to national economies, particularly those of small island developing states (SIDS), 90 per cent of which have coral reefs and over 75 per cent of which have mangroves.

Ecosystems that can no longer provide their full ecological services have a social and economic 'cost' that can be felt locally and many miles away. Degradation of coral reefs and mangroves may, and in some cases already does, cause:

- Reduced fish catches and tourism revenue in coastal communities, and potentially even loss of food security and malnutrition due to lack of protein.
- Loss of export earnings and decline of the tourism industry.
- Increased coastal erosion and destruction from storms and catastrophic natural events, which affects coastal residents, tourism operations and many other economic sectors.

SHORELINE PROTECTION

Reefs and mangroves naturally form barriers and thus inevitably provide some shore protection, a fact long recognized by coastal communities, fishers and vessels which use the sheltered waterways behind these ecosystems. Both reefs and mangroves can themselves be damaged by strong winds and waves, and so their buffering capacity is a balance between their resilience and their vulnerability. The current consensus is that:

- Reefs and mangroves play an important role in shore protection under normal sea conditions and during hurricanes and tropical storms. At least 70-90 per cent of the energy of wind-generated waves is absorbed, depending on how healthy these ecosystems are and their physical and ecological characteristics.
- In a tsunami, the buffering capacity of reefs and mangroves is more variable and often reduced because of the different structure and form of the waves and their much greater force. Distance from the earthquake epicentre, the presence of inlets and headlands, the gradient of the continental slope, shoreline elevation, the presence of dunes and other vegetation, and density of habitation and infrastructure seem to explain most of the variation.

PROS AND CONS OF REHABILITATION AND RESTORATION

Both reefs and mangroves will recover naturally once a stress has been removed, but this can be slow; for example, the reefs most seriously damaged by the tsunami may take five to ten years to recover. New growth of coral colonies and

mangrove trees, and recruitment of coral larvae and mangrove seedlings, is balanced by erosion and breakdown from both human-induced and natural stresses. The chronic human impacts faced by these ecosystems are tending to slow recovery, and the highest priority is to reduce and eliminate these stresses. It is tempting to try to speed recovery of an ecosystem by active restoration, or repair. However, this is rarely totally successful because of the difficulties involved in re-establishing full biodiversity and ecological processes:

- Mangrove restoration is relatively simple and large areas of new forest are being created using volunteers and local labour. However, achieving a mangrove forest with a full complement of biodiversity is a more complex and long-term process, and it is questionable whether any programmes have yet achieved this.
- Reefs, involving numerous species with very different life histories and poorly understood growth and reproductive characteristics, are more difficult to restore. Many attempts have been made using a variety of techniques. Most methods are costly and require considerable skill, and there are few examples of successful sustainable reef restoration over large areas.

CORAL REEF AND MANGROVE MANAGEMENT IN THE FUTURE

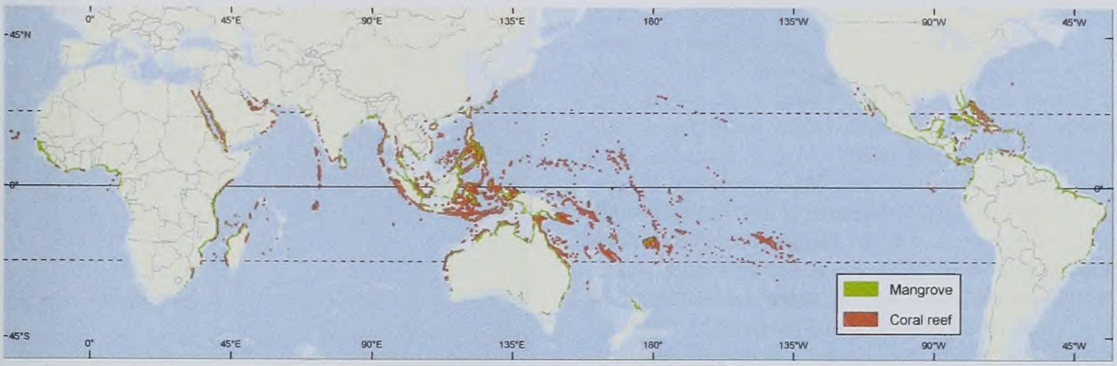
Investing in environmentally sustainable management and development of the coast will be more cost effective than restoring human livelihoods and ecosystems after a catastrophe. The relatively small amount of damage inflicted on coral reefs and mangroves by the 2004 tsunami demonstrated the resilience of these ecosystems to natural disturbance, but the worldwide public concern generated also revealed our awareness of their vulnerability.

- The devastation recently wrought by hurricanes and tropical storms testifies to the priority that must be accorded to the maintenance and enhancement of the resilience of natural coastal barriers such as reefs and mangroves.
- Post-tsunami and hurricane reconstruction efforts provide an opportunity to introduce and expand good coastal management practices. These may indeed help to mitigate damage from future tsunamis but, since these are infrequent events, the more important consequence is mitigation of the impacts of the more certain, but gradual, changes due to global warming.
- Short-term, small-scale rehabilitation programmes should not take precedence over activities directed at the root causes of the decline in reef and mangrove health. Key tools include integrated coastal management, marine protected areas, and monitoring and assessment for adaptive management.
- Governments, civil society and the private sector must recognize that, as with other benefits, there is a price to pay for maintaining these ecosystems. However, this is much lower than the benefit received. For example, the estimated average operational management cost of a marine protected area is US$775 per km^2, or less than 0.2 per cent of the estimated global value of a square kilometre of reef or mangrove.
- Many of the world's wealthiest nations have jurisdiction over these ecosystems – more than 30 per cent of reefs are in countries classified as highly developed. They also have strong links with less developed countries struggling with their management. Political will and concerted action are needed – coral reefs and mangroves are in the front line, and calling for attention.

S Wells

D Sato/UNEP/Topham

Global status of reefs and mangroves



Mangroves and tropical coral reefs

DISTRIBUTION

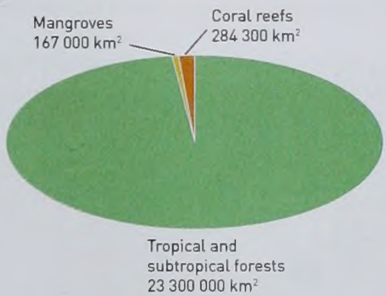
Of the 177 countries in the world, rather less than half (44 per cent) have tropical coral reefs and about half have mangroves. Our knowledge of the distribution of coral reefs and mangroves is now relatively good, as a result of regional and global mapping programmes using navigational charts, satellite imagery and aerial photography, as well as more detailed field surveys.

Both ecosystems occur principally in the tropics, with South-East Asia a major centre. Distribution between countries is very unequal. Australia and Indonesia each have about 50 000 km² of reef and account for nearly 35 per cent of the world's reefs, and Indonesia alone has 23-25 per cent of the world's mangroves. In general, other countries have less than 10 000 km² of reef and less than 1 000 km² of mangroves (Spalding et al., 1997; 2001).

STATUS

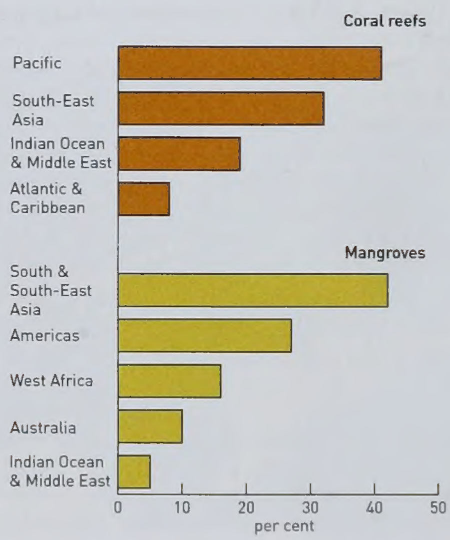
The coastal biome, which makes up only 4 per cent of the

Fig. 1: **Area of coral reefs and mangroves**



Coral reefs and mangroves are among the world's rarest ecosystems. Reefs cover an estimated 284 300 km², or just 1.2 per cent of the world's continental shelf area (Spalding et al., 2001). The total area of mangrove forest is less certain but is even smaller, estimated at between 167 000 km² (Valiela et al., 2001) and 181 000 km² (Spalding et al., 1997). As a comparison, tropical and subtropical forests cover 23.3 million km², an order of magnitude larger (Millennium Ecosystem Assessment, 2005).

Fig. 2: **Distribution of tropical coral reefs and mangroves**



planet's total land area, is home to one-third of the world's population, and this population is predicted to double over the next 15 years. In many countries, such as island nations and those with inhospitable and arid interiors, humankind lives almost entirely on the coast. With the exception of some isolated atolls, all reefs and mangroves lie adjacent to the coast; more than half these ecosystems occur within 25 km of urban centres inhabited by 100 000 or more people (Millennium Ecosystem Assessment, 2005). Not surprisingly, the health and extent of both reefs and mangroves have declined dramatically over the last century.

Trends in reef health are well documented as assessments are carried out at regular intervals, through numerous monitoring programmes, the results of which are published in the biennial *Status of the World's Reefs Reports* (Wilkinson, 2004), the regional World Resources Institute's *Reefs at Risk* reports (Burke and Maidens, 2004; Burke et al., 2002) and many national reports.

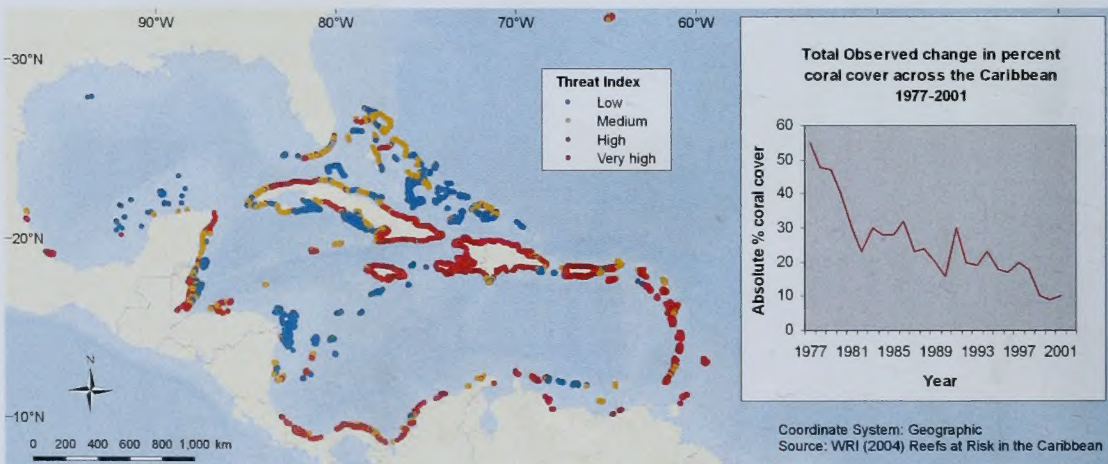
Results from monitoring programmes indicate that about 30 per cent of the world's reefs are seriously damaged, with possibly no pristine reefs at all remaining, and it has been predicted that 60 per cent of reefs will be lost by 2030 (Wilkinson, 2004). Using information on existing and potential threats to reefs in 1998, the World Resources Institute suggested that 27 per cent of all reefs are potentially at high risk and a further 31 per cent are at medium risk of damage (Bryant et al., 1998). More recent regional predictions, using the same method, paint an even more disturbing picture. A 2000 analysis estimated that human activities potentially threaten 88 per cent of the reefs of South-East Asia, with 50 per cent at 'high' or 'very high' risk and only 12 per cent at low risk (Burke et al., 2002).

As yet there are no equivalent global mangrove

Carysfort Reef, the largest and most luxuriant reef in the Florida Keys, United States, in 1975 (higher) and 2004 (lower) showing the catastrophic decline of living coral cover.

Reefs at risk in the Caribbean

*Nearly two-thirds of reefs in the Caribbean are potentially at risk from human activities, according to a 2004 report, with over 40 per cent at 'high' or 'very high' risk, and about 28 per cent at low risk (Burke and Maidens, 2004). In this region, elkhorn (*Acropora palmata*) and staghorn (*A. cervicornis*) corals have undergone massive die-offs (Gardner et al., 2003).*



assessments, but several studies have shown this ecosystem to be as much at risk as coral reefs. The amount of mangrove lost varies widely among countries but, where data are available, mangroves are on a declining trend. An estimated 35 per cent of mangrove forest has disappeared in the last two decades (Valiela et al., 2001), and some countries have lost 80 per cent of cover (Spalding et al., 1997). The average annual rate of disappearance (or conversion to other forms of land use) is estimated at 2.1 per cent, with the greatest rate of loss in the Americas (3.6 per cent). The annual rate of loss of mangroves thus exceeds the rate of disappearance of tropical rainforests (0.8 per cent) (Valiela et al., 2001). Estimates for some locations suggest that rates of mangrove loss may be as high as 50 per cent a year (Alongi, 2002).

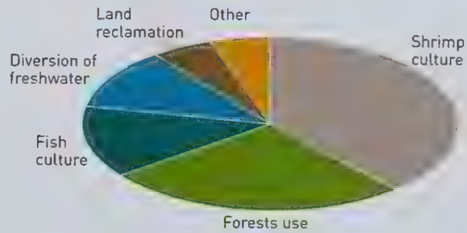
Over the last few decades there have been major changes in the appearance and quality of reefs and mangroves, the result of a combination of many 'drivers' or threats. These have both direct and indirect impacts that often trigger an escalating series of problems.

Many reefs, for example, are undergoing a shift from a coral-dominated to an algal-dominated state. Corals have been disappearing as a result of bleaching, disease, storm damage and a range of human activities, including overfishing, use of destructive fishing gear, anchor damage and pollution. At the same time, algae have increased as herbivores and grazers, such as sea urchins and some fish species, that keep them in control have declined through disease and overfishing. Algae have further increased as a result of nutrient pollution. Where coral cover has started to increase there are indications that the so-called framework-building corals (e.g. *Acropora, Montastrea*) that once dominated are being replaced by corals that contribute

The brown seaweed Chnoospora *overgrowing branching corals.*

Y Latypov

Fig. 3: **Area of mangrove lost to human activities** (per cent)



Source: Valiela et al., 2001

little to the main structure of the reef (e.g. *Agaricia*) (Hughes et al., 2003; Knowlton, 2001).

Degradation of mangroves leads to long-term changes in the ecology of large areas of coastline. In particular, conversion of mangroves to shrimp farms, and the subsequent aeration and use of fertilizers, alters the composition and structure of the soil. Eventually ponds are abandoned, sometimes after only two to ten years, as they are no longer suitable for production (Stevenson, 1997). There is little chance of mangrove regeneration in the remaining barren lands. Leading causes of mangrove forest loss and degradation are conversion for aquaculture, use of mangroves for timber for construction and other functions, and for fuelwood and charcoal, conversion to rice paddies, and freshwater diversion and coastal development for tourism and other purposes (Valiela et al., 2001).

THREATS

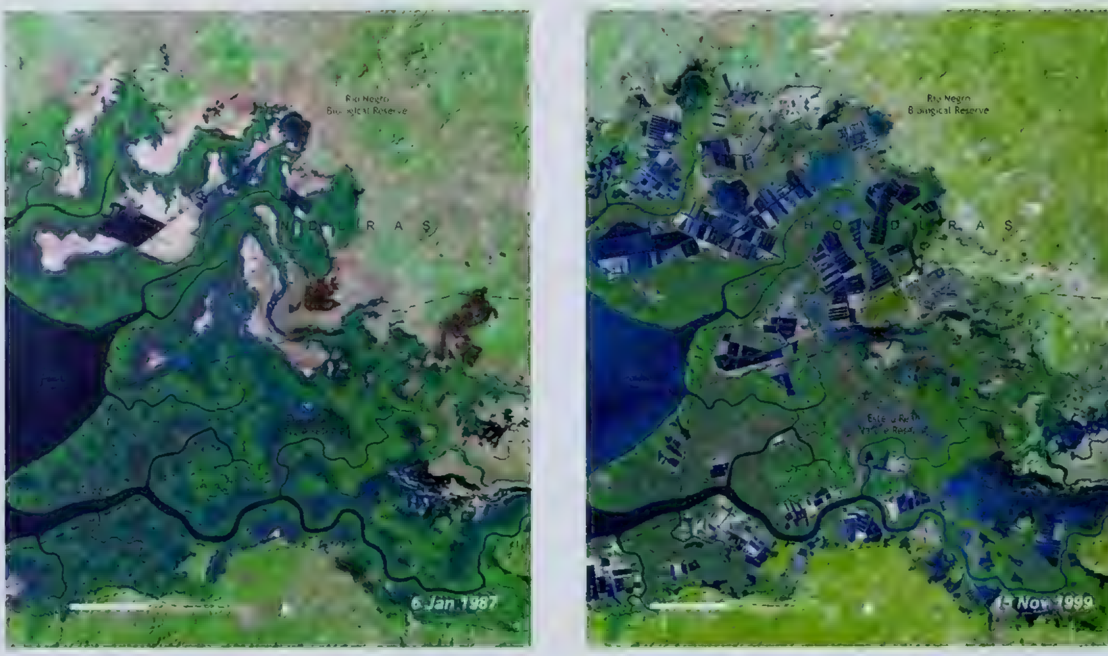
Overexploitation and destructive fishing

Many commercial fish species, such as rabbitfish (Siganidae), feed on algae, and their removal can result in excessive algal overgrowth of corals. Removal of 'keystone' species (those that play a particular role in an ecosystem) – such as triggerfish which prey on sea urchins – may be the cause of urchin population outbreaks which further degrade corals through bioerosion. Dynamite, small-mesh nets and nets that are dragged over the seabed, although illegal in many countries, are still used and cause widespread physical damage as well as removing or killing immature fish and other species of no commercial value.

Habitat loss

Mangroves can be completely wiped out when forests are cleared for salt production operations, for industrial, residential and tourism development, or, particularly, for aquaculture. In contrast, coral reefs generally suffer from

UNEP



In Honduras, shrimp farms have progressively transformed the coast of the Gulf of Fonseca since the early 1970s. Although there were still large areas of mangrove in 1987, by 1999 the only substantial forests were in protected areas such as Estero Real Nature Reserve (UNEP, 2005a).

a gradual decline in quality rather than a sudden disappearance. However, mining for corals for use as building materials can eliminate, or reduce to rubble, large areas of reef. Although coral mining is illegal or regulated in most countries, it is still having a major impact in India, the Maldives, Sri Lanka and Tanzania (Wilkinson, 2004).

Land-based sources of pollution

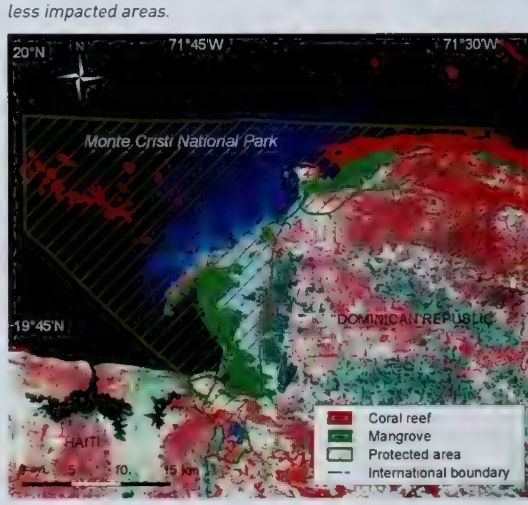
More than 77 per cent of the pollutants entering the oceans originate on land, and 44 per cent of these pollutants come from improperly treated wastes and run-off (Cicin-Sain et al., 2002). The nutrient content of the oceans has increased dramatically in recent years as a result of fertilizer and other agricultural run-off, sewage and aquaculture waste. Nutrients such as nitrogen and phosphorus deplete oxygen in the water and promote the growth of algae on reefs (Hughes et al., 2003).

Many coastal development activities, such as residential, tourist, industrial and port development, involve land reclamation and dredging which invariably results in sediment being stirred into the water column. This reduces light penetration, may directly smother corals and can damage mangroves. Construction activities inland, agriculture and deforestation, and poor management also contribute to increased sediment.

Disease

Coral diseases, rarely recorded until the 1970s, have had a catastrophic effect on reefs, particularly in the Caribbean, affecting 100 hard and soft coral species in 54 countries. The cause is still largely unknown, although

Sediment plume in Monte Cristi National Park, Dominican Republic. Inland deforestation is causing sediment run-off on to nearby coral reefs. As a result, coral cover tends to be low compared with other less impacted areas.



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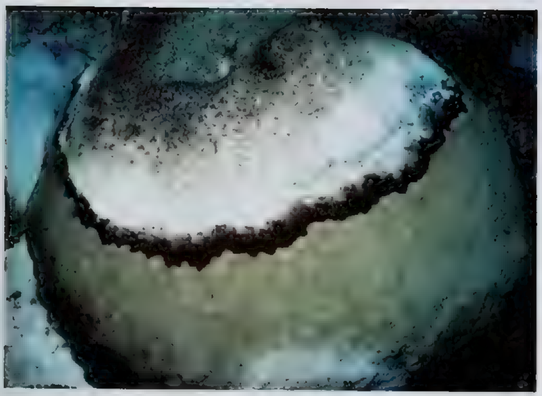

A W Bruckner

Coral attacked by black-band disease.


Thomas Heeger

Fishing with dynamite in the Philippines.

both fungi and bacteria have been identified as pathogens in two cases (Porter, 2001; UNEP-WCMC, 2003). There are indications that abrasion of massive corals through tourist activities may make corals more susceptible to disease (Hawkins et al., 1999).

Climate change

There is now general consensus that extreme storm events are becoming more frequent, and sea levels and sea surface temperatures are rising as a result of global warming. Reefs are already suffering from bleaching events that have increased significantly since 1975. In the Caribbean bleaching events are predicted to become an annual event as current sea surface temperatures are in the upper temperature threshold for coral survival (Gardner et al., 2005; Hughes et al., 2003). Tropical storms are forecast to become even more frequent and/or more intense (Trenberth, 2005), and this will compound the problem, causing more damage to both reefs and mangroves and resulting in shorter recovery times between events (Hughes et al., 2003).

The change on reefs from coral to algal dominance, and from framework-building species to non-framework species, may also compromise their ability to keep pace with rising sea levels (Bellwood et al., 2004; Gardner et al., 2003).

Furthermore, by 2100, rates of calcification (the process by which calcium is formed) on reefs may have decreased by 17-35 per cent of pre-industrial levels as a result of high levels of dissolved carbon dioxide in the oceans (these are now 380 parts per million (ppm), compared with 280 ppm two centuries ago). This will cause weakening of coral skeletons and slower growth rates, making reefs even less effective as breakwaters (Feeley et al., 2004; Kleypas et al., 1999).

Other threats

Individual tourists, tourist boats and anchors may have only a minor impact, but over time and in large numbers the impact becomes significant (Hawkins et al., 1999; Zakai and Chadwick-Furman, 2002). Spills of oil and toxic chemicals, and dumping of other wastes, cause localized impacts to both reefs and mangroves. The introduction of alien species is a threat to marine ecosystems that is growing rapidly with increased shipping and susceptibility in systems degraded by other stresses. Marine plants and animals can be transported immense distances on the hulls of vessels or in ballast water. Non-indigenous sessile species have been introduced to reefs in Guam via ships' hulls, and other alien species are spreading on the reefs of Hawaii, outcompeting native species (Eldredge, 2003).

Value of ecosystem services

The Millennium Ecosystem Assessment (Millennium Ecosystem Assessment, 2005) defines four categories of ecosystem services:

- provisioning – e.g. food, medicines, construction materials
- regulating – e.g. protection of shorelines, water quality maintenance
- cultural – e.g. tourism, spiritual beliefs
- supporting – e.g. maintenance of basic life support systems.

Coral reefs and mangroves provide benefits under all four categories.

C Ravilious

Ecosystem services	Coral reefs	Mangroves
REGULATING	Protection of beaches and coastlines from storm surges and waves Reduction of beach erosion Formation of beaches and islands	Protection of beaches and coastlines from storm surges, waves and floods Reduction of beach and soil erosion Stabilization of land by trapping sediments Water quality maintenance Climate regulation
PROVISIONING	Subsistence and commercial fisheries Fish and invertebrates for the ornamental aquarium trade Pharmaceutical products Building materials Jewellery and other decoration	Subsistence and commercial fisheries Aquaculture Honey Fuelwood Building materials Traditional medicines
CULTURAL	Tourism and recreation Spiritual and aesthetic appreciation	Tourism and recreation Spiritual – sacred sites
SUPPORTING	Cycling of nutrients Nursery habitats	Cycling of nutrients Nursery habitats

Techniques for valuing ecosystem services are still relatively new and untested, and the results of such calculations must be interpreted with care. Putting a monetary value on an ecosystem, however, can help to demonstrate why its survival is important (IUCN/TNC/World Bank, 2004; Turner et al., 2003). Economic values can be calculated from the cost of the products (e.g. fish) and services (e.g. tourism) derived from an ecosystem, or from the cost of replacing a service (e.g. building seawalls where natural storm protection has been lost).

There is, however, no single agreed total value for all coral reefs or all mangroves, or even for the different services provided by these ecosystems. Values vary according to:

- The location – e.g. reefs that are major tourist destinations will have a higher value in terms of diving and other reef-related activities than those where tourism has not been developed.
- The length of time being considered and whether a prediction for the future is involved

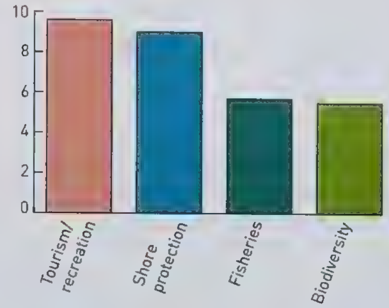
(e.g. all reefs are potentially of value for diving tourism but some may have no value at present).
- The 'beneficiaries' of the service, since some people will place a higher value on it than others.
- The method used and the assumptions made.

Furthermore, it is hard to calculate the economic value of the aesthetic and ethical benefits of ecosystems, or of the service some ecosystems provide through cycling nutrients. Estimates of the 'total' economic value of an ecosystem thus vary considerably and there is a risk that using this approach underestimates the ecosystem's social benefits and overall importance. This means that it is not always wise to use ecosystem valuations for policy making and investment decisions (IUCN/TNC/World Bank, 2004). For example, the apparent higher value assigned to mangroves than coral reefs (see Fig. 4) should not be interpreted to mean that they have a higher management priority. It is also true that many of the activities that bring benefits, such as fishing and tourism, also damage reefs and mangroves, and only careful management will allow the full values to be materialized.

However, if these limitations are taken into account, an economic valuation can help to demonstrate the major role that reefs and mangroves play in the lives of many people. Studies to date have shown that most benefit comes from provisioning services (i.e. fisheries and, for mangroves, timber and fuelwood), cultural services (tourism) and regulating services (shore protection).

The total annual economic value of reefs has been estimated at between US$100 000 and US$600 000 per km^2 (Cesar et al., 2003; Constanza et al., 1997) and the value of mangroves even higher, at more than US$900 000 per km^2 (Constanza et al., 1997). Figures are, however, very variable as some national estimates show:
- Sri Lanka's coral reefs have been valued at between US$140 000 and US$7.5 million per km^2 over a period of 20 years (Berg et al., 1998).
- In American Samoa, mangroves, which cover less than 0.5 km^2, have an estimated value of US$104 000 per km^2 (total value of about US$50 million a year) and reefs, which cover 222 km^2, are estimated at US$14 300 per km^2 (total value of US$318 million a year) (Spurgeon and Roxburgh, 2005).
- In Thailand, very high values of US$2.7 million to US$3.5 million per km^2 have been calculated for mangroves (Sathirathai and Barbier, 2001).

Fig. 4: **Economic value of the main ecosystem services of coral reefs** (billion US$)



Source: Cesar et al., 2003

Some of the variation can be explained by the location of the ecosystem. The value of reefs and mangroves for shore protection (often measured per linear kilometre) depends on the activities under way or planned along a particular stretch of coast. In Indonesia, reefs have been valued as follows (Cesar, 1996):
- Reefs adjacent to sparsely populated areas where agriculture is the main activity: US$829 per km, based on the value of agricultural production that would be lost if there were no protection.
- Reefs adjacent to areas of high population densities: US$50 000 per km, based on the cost of replacing housing and roads if coastal protection were lost.
- Reefs in areas where tourism is the main use: US$1 million per km, based on the cost of maintaining sandy beaches.

Similar values have been obtained for the Caribbean, varying from US$2 000 to US$1 million, with the highest values in areas heavily developed for tourism (Burke and Maidens, 2004).

There are also several methods for valuing mangroves. The storm protection value of mangroves in Sri Lanka (before the tsunami) was put at US$7 700 per km^2 a year using a linear value (UNEP/GPA, 2003). A study in Indonesia, in a different approach, calculated the erosion control value of mangroves as being equivalent to US$600 per household per year (Ruitenbeek, 1992).

Regulating services – shoreline protection

S H Grady

Hotel built behind mangroves, Kenya.

Although reefs and mangroves form natural barriers along the coast and thus inevitably provide some protection to the shore, there is surprisingly little scientific data to back this up. Most of the evidence is observational and anecdotal, and relates to normal wave energy and storms. The calm lagoons inside reefs and behind mangroves are immediately evident on tropical coastlines. Fishers use these sheltered waters as navigation routes and for fishing, particularly during bad weather or the rough season monsoons. Holiday makers and tourists benefit from the sheltered waters for numerous recreational activities. The breakwater role of reefs is emphasized by the importance accorded to the channels through them. These allow safe passage to the lagoon and shore for fishing, navigation and recreational activities, particularly in bad weather, a significance recognized by both coastal communities and port authorities.

Coastal communities are often aware of the particular protection afforded by mangroves. In India (Dahdouh-Guebas et al., 2005) and the Philippines (Walters, 2004), villagers tell of how they have been protected from cyclones and typhoons in locations where mangroves are intact, but suffer where mangroves have been converted to shrimp farms or otherwise lost. In Orissa, India, a powerful cyclone in 1999 and associated waves caused extensive damage and human mortality, but communities protected by mangrove belts were less affected (Mangrove Action Project, 2005). In Viet Nam, mangroves have been observed to limit damage from cyclone waves and tsunamis and are said to have led to large savings on the costs of maintaining sea dykes (Ha, 2003; Tri et al., 1996).

In southern India, the distinct differences between the Gulf of Mannar and Palk Bay, caused by the protection provided by reefs, have led to these seas being equated with men and women by local villagers. The former is considered 'male' because waves hit the reef and subside in force before they reach the shore. The latter is considered 'female' because waters are generally calmer, but, if disturbed by storms, cause greater damage due to the lack of a reef. Fishing communities on Pamban, an area lying between the two seas, still remember the 1964 cyclone that washed away one village, while those behind reefs survived (Whittingham et al., 2003). Further north, in Chidambaran District the shore protection role of mangroves is recognized by local people where a 113 km^2 forest is used

as a sacred grove and is traditionally known in Tamil as *Alaithi Kadukal*, which means 'the forest that controls the waves' (WWF, 2005).

Both reefs and mangroves also play a role in the accretion of coastlines. Reefs produce sand that forms and replenishes sandy beaches and islands, the sediment accumulating when corals and other calcified organisms break down after their death. Mangroves help to stabilize coastal land, by trapping sediment washed down in rivers or from more general run-off. Remains of rows of mangroves planted to stabilize the coast by early generations of Maoris can still be seen in New Zealand (Vannucci, 1997).

The role of reefs as breakwaters is also demonstrated by the many artificial structures that are being installed for shoreline protection in locations with no natural reefs. These often have a negative impact, in terms of creating unwanted longshore drift, but they nevertheless show how reef-type barriers influence wave action, even being installed to improve surfing conditions (Jackson et al., 2002).

Although the general buffering capacity of reefs and mangroves thus seems obvious, the mechanical processes involved are complex, and the extent to which they provide shore protection compared with man-made barriers and other natural features is not yet fully understood. Furthermore, the reef and mangrove ecosystems are themselves damaged by events such as storms and tsunamis. Hurricanes, for example, can reduce coral cover significantly (Gardner et al., 2005). Mangroves can be destroyed or seriously degraded by hurricanes, through defoliation and uprooting by the wind, erosion of the shoreline by waves and burial under sediment. In 1999 Hurricane Mitch destroyed 97 per cent of the mangroves of Guanaja, one of the Bay Islands in Honduras (Cahoon and Hensel, 2002). Thus the buffering capacity of both ecosystems is a balance between their resilience and their vulnerability, with many factors involved. A healthy coral reef or mangrove, in the absence of human impact, acts as a self-repairing breakwater, with growth in equilibrium with the erosion caused by waves, storms and other processes.

WIND-GENERATED WAVES AND STORMS

The waves normally seen on the ocean are generated by wind, and have most of their energy in the surface waters. The reef flat (the zone of a reef extending seaward across the lagoon) and the reef crest (the seaward edge of the reef flat) absorb most of a wave's force, often up to or more than 90 per cent (Brander et al., 2004; Lugo-Fernandez et al., 1998; Roberts and Suhada, 1983). The greater the width of reef flat between the reef edge and the shore, the more wave energy is lost. In Egypt, for example, the reef flat and reef crest of the fringing reef off the tourist resort of Hurghada dissipate wave energy considerably, protecting marinas and beaches (Frihy et al., 2004).

S Wells

The lagoon behind the fringing reef here in northern Zanzibar provides a shallow sheltered area where many activities can be undertaken.

The amount of energy reduction also depends on the extent of fragmentation of the reef, as a continuous reef acts more as a breakwater than a reef that is broken by channels. The state of the tide and the depth of water over the reef – at low tide a reef affords more protection – and whether it 'plunges' on to or 'spills' over the reef top also play a role (Gourlay, 1994; Kabdali and Turker, 2002). Quantifying what the reduction in wave energy may mean in terms of shore protection is more difficult. In Sri Lanka, however, it has been estimated that with current rates of erosion and assuming that 1 kilometre of reef protects 5 kilometres of shoreline, 1 km^2 of coral reef can prevent 2 000 m^2 of erosion a year (Berg et al., 1998).

Mangroves dissipate the energy and size of waves as a result of the drag forces exerted by their multiple roots and stems. Wave energy may be reduced by 75 per cent in the wave's passage through 200 metres of mangrove (Massel et al., 1999) but, as with coral reefs, other factors also have an influence, including coastal profile, water depth and bottom configuration. One study suggested that a 1.5-km belt of mangrove may be able to reduce entirely a wave one metre high (Mazda et al., 1997).

A Baird

Large boulder coral washed up on an Aceh beach following the tsunami of December 2004.

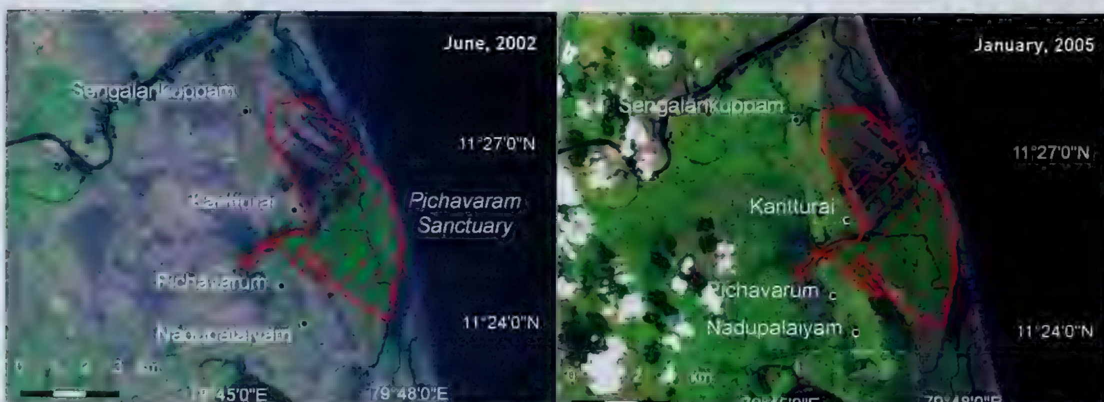
TSUNAMIS

Compared with a wind-generated wave, a tsunami has a much longer wave length and the wave energy is distributed throughout the entire water column and is on a much greater scale. As a tsunami approaches the shore and water depth decreases, the wave height increases dramatically as energy is converted to surface layers, this effect being more pronounced on gradually shallowing shores (Kowalik, 2004; Mojfeld et al., 2000). Tsunamis can cause substantial damage at locations protected from wind-generated waves, as they tend to accelerate through channels and up inlets, rapidly increasing in height. They can also be reflected off obstacles and travel in different directions (Yeh et al., 1994). It is thus perhaps not surprising that the roles of reefs and mangroves as buffers in the 2004 tsunami, and the damage they received, varied considerably.

Despite initial fears, both ecosystems were less badly damaged than expected even on reefs in Aceh, Indonesia, which were within 300 km of the epicentre (Baird et al., 2005). In Thailand, of 175 reef sites surveyed on the Andaman coast after the tsunami, more than 60 per cent had little or no damage; 13 per cent were seriously damaged, however. Shallow reefs on wave-exposed islands and shorelines were most vulnerable, as were the northernmost coast and offshore islands (Phongsuwan and Brown, in press). At some sites, differences were even more localized: at Patong Bay, Phuket, reefs in the south were badly damaged but those in the north were almost untouched, a pattern that was reflected in the destruction on land (Edwards, 2005). Post-tsunami surveys in Thailand and Aceh show that most damage was in the form of overturning of poorly attached boulder corals, breakage of branching corals, and smothering of the reef with sediment (Baird et al., 2005; Phongsuwan and Brown, in press). Much greater damage was sustained by reefs directly affected by the earthquake. Reef flats, with once diverse coral communities, have been permanently uplifted above the high water mark in many coastal areas of Aceh and the Andaman and Nicobar islands (B. Brown, pers. comm.).

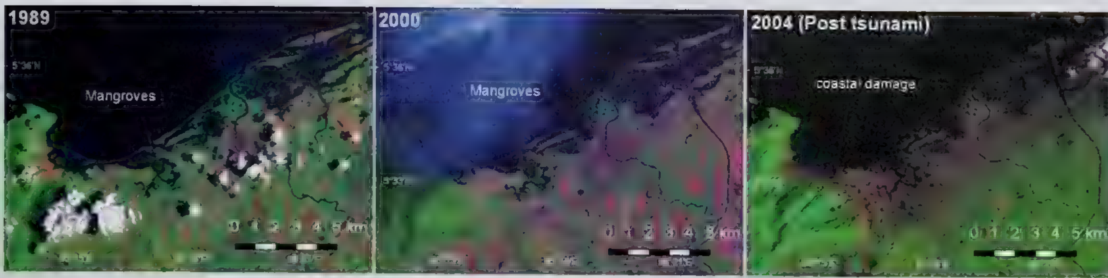
An analysis by UNEP/GRID of more than 50 sites affected by the tsunami, using pre- and post-satellite imagery, indicated that there was greater coastal flooding behind coral reefs (Chatenoux and Peduzzi, 2005), perhaps because channels through the reef accelerated the flow. The same result was found in Aceh

UNEP-WCMC



Many parts of the coast of Tamil Nadu in India were severely hit by the tsunami. Three villages behind the mangroves in Pitchavaram Sanctuary survived whereas the two in front were lost (Danielsen et al., 2005; Kathiresan and Narayanasamy, 2005). This could, however, have been due to the reduced force of the wave, as the continental slope drops to deep waters much more sharply here, compared with areas further south which suffered greater damage (Wood, 2005).

UNEP-WCMC



The once extensive mangroves around Banda Aceh in Sumatra, Indonesia, an area which suffered devastating damage and loss of life in the tsunami, had been largely replaced by shrimp farms, covering 360 km² (UNEP, 2005b). Although loss of mangroves could have contributed to the destruction, the area was also very close to the epicentre of the tsunami, and thus vulnerable to substantial impact.

(Baird et al., 2005), and studies on the Queensland coast of Australia have also shown that historically tsunamis have breached the Great Barrier Reef through passes in the reef (Knott, 1997).

Some studies have suggested that, in certain locations, reefs did provide protection. In Sri Lanka, at Hikkaduwa where the reefs are in a better condition than many in the country – and are protected in a marine park – the tsunami caused damage to a distance of only 50 metres inland and waves were only 2-3 metres high. At Peraliya, just 3 km to the north but where the reefs have been extensively affected by coral mining, waves were 10 metres high, and damage and flooding occurred up to 1.5 km inland (Fernando et al., 2005, Liu et al., 2005). Detailed analysis of these areas is still needed, as other factors may also be involved. Dunes were particularly important in providing protection in Sri Lanka (Liu et al., 2005).

Initially, there were many observations suggesting that mangroves both dissipated the force of the tsunami and caught the debris washed up by it, and thus helped to reduce damage (IUCN, 2005). In several cases, mangroves were also instrumental in saving lives by preventing people caught in the backwash of the wave from being pulled out to sea. However, as with coral reefs, subsequent studies showed that the benefit of mangrove protection was rather variable. In India, bathymetry and coastal profile were most important in determining the impact, but less erosion was observed in the Andamans behind mangroves than where there were no mangroves (Department of Ocean Development, 2005).

A survey of 24 lagoons and estuaries along the south-west, south and south-east coasts of Sri Lanka which suffered the greatest damage showed that where good quality mangrove communities occurred there was little destruction to the coast, and the mangroves themselves were not badly harmed. However, forests dominated by less typical mangrove species (i.e. those that had been degraded in the past and were no longer dominated by genera such as *Sonneratia* or *Rhizophora*) were damaged (Dahdouh-Guebas et al., 2005). It therefore seems that the 'quality' of the mangrove forest contributes in large measure to its buffering capacity, in addition to its size and the extent of regrowth if it had previously been cleared. Tree density may certainly be important: one study indicated that a 100 metre-wide belt of mangroves, with trees at a density of 30 per 100 m², would be sufficient to reduce the flow pressure from a tsunami by as much as 90 per cent (Hiraishi and Harada, 2003).

Analyses of satellite images of a large number of tsunami-impacted sites do not show clear correlations between the presence of mangroves and reduced shoreline damage (Chatenoux and Peduzzi, 2005; Wood, 2005). In many cases the locations where mangroves have been reported to have helped protect the shoreline were out of the main path of the wave, or were adjacent to deeper water, and thus less susceptible to serious damage. These findings demonstrate the importance, in developing predictive models, of carefully analysing every aspect of a site, both at the broad scale where satellite imagery can be useful and through detailed field surveys and on-the-ground studies.

The general picture emerging since the tsunami is that reefs and mangroves were not the main factor influencing the extent of damage on the coastline. Nearshore bathymetry and coastline profile are probably the key factors determining the force of a wave at any particular coastal location. Shores adjacent to deep water tended to be less affected than those next to shallow sloping shelves, regardless of the presence or absence of reefs. The shape of the coastline is also influential, with headlands often providing protection while bays and inlets act as funnels, restricting and focusing the force of a wave. More research is required before it will be possible to predict where, and in what way, a reef or mangrove will help to reduce the impact of a tsunami.

Other ecosystem services

OTHER REGULATING SERVICES

Climate and global carbon cycle

Emissions of carbon dioxide from fossil-fuel combustion and land-use changes are the leading cause of the build-up of greenhouse gases. Forests, as well as crops, soil and other organic matter, take up carbon (carbon sequestration) and help to reduce the rate of global warming. Mangroves fix and store significant amounts of carbon (Alongi, 2002) and they play an important role in carbon sequestration, currently absorbing an estimated 25.5 x 10^6 tonnes of carbon a year (Ong, 1993).

Although reefs play an important role in the carbon budget, contributing 7-15 per cent of global calcium carbonate production, they do not help with carbon sequestration. Sedimentary carbonates, including corals, coralline algae and the shells of other marine organisms, are the largest reservoir of carbon on Earth, and so fluctuations in the global calcium carbonate budget influence atmospheric carbon dioxide concentration. However, the chemistry of the system is such that although the oceans themselves are a 'sink' (i.e. they take up carbon dioxide), reefs are 'sources' or net producers of carbon dioxide, albeit on a small scale in terms of the global carbon budget, through the process of calcification (Suzuki and Kawahata, 2004).

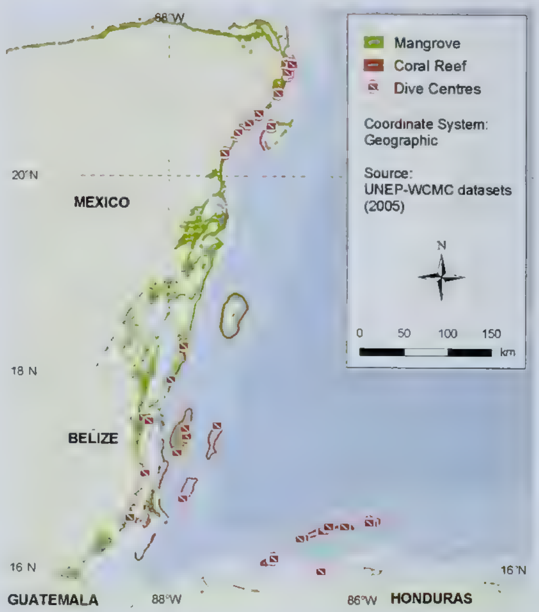
Water quality

Mangroves are capable of absorbing pollutants such as heavy metals and other toxic substances (Lacerda and Abrao, 1984), as well as nutrients and suspended matter (Ewel et al., 1998). This makes them natural wastewater filters, preventing many pollutants from reaching deeper water (Robertson and Phillips, 1995; Tann and Wong, 1999).

CULTURAL SERVICES

Tourism

Coral reefs add significantly to the value of coastal tourism, supporting activities such as scuba diving, snorkelling and glass-bottom boat operations. They also contribute to the formation of white sandy beaches. Tourism is the world's largest industry, with 694 million international tourist arrivals generating revenues of over US$500 billion in 2003. The tourism industry is a major employer and source of foreign exchange and is growing rapidly; it is expected to reach 1.6 billion arrivals by 2020. Beach-based leisure tourism constitutes a large, and possibly the fastest growing, sector. In Egypt, for example, the tourism sector as a whole accounts for more than 11 per cent of gross domestic product (GDP), and coral reefs have been central to the extremely rapid development of beach-based and diving tourism in south Sinai since the 1990s; this area now accounts for some 25 per cent of tourism's contribution to national GDP (Jobbins, 2004).



The number of dive operators along the Meso-American Barrier Reef has increased dramatically in recent years, reflecting the growth of this leisure activity. In 2000, reef divers – numbering about 3.6 million – made up 10 per cent of all tourists to the Caribbean. Divers, however, contributed 17 per cent of tourism revenue, spending about US$2 100 per trip, compared with US$1 200 for tourists in general. It has been estimated that in 2000 the net annual benefits from diver tourism in the Caribbean amounted to US$2.1 billion, with US$625 million being spent directly on diving on reefs (Burke and Maidens, 2004).

The 2004 tsunami brought home the economic value of coastal and reef-based tourism, since this is vital to the economies of the Maldives, Sri Lanka and Thailand. In Sri Lanka, coastal tourism contributed about US$20 million a year to the national economy in the mid-1990s (Berg et al., 1998). A study in 2003 of the reefs of the Phi Phi Islands in Thailand, subsequently heavily damaged by the tsunami, valued them at US$624 300/km^2 a year for tourism and

S Wells

A mangrove boardwalk for tourists on Wasini Island in southern Kenya, managed by a local women's group, generates several thousand dollars a year which are used for maintaining the boardwalk and for community development activities (IUCN, 2004).

recreation, with a total value of US$205 million a year (Seenprachawong, 2003). This provides a major incentive for careful management of the reefs post-tsunami, to ensure that they recover rapidly and continue to provide tourism benefit.

Mangroves are not traditionally thought of as tourist attractions or suitable sites for recreation, but this is changing fast with the realization that this ecosystem provides a fascinating educational experience and also harbours a range of unusual species that can be easily observed once boardwalks have been installed. Visits to mangroves and birdwatching tours are now generating significant revenue for local communities.

PROVISIONING SERVICES

Fisheries and other marine products

Coral reefs and mangroves support numerous different types of fishery: artisanal, commercial and recreational; food, curios and souvenirs, bait, and items for decoration; and fish, lobsters, crabs, molluscs, sea cucumbers and many other species. However, much of the harvesting of these species, as well as of species taken for non-food purposes, is unsustainable, and current economic benefits may thus be short term.

Of the estimated 30 million small-scale fishers in the developing world, most are dependent to some extent on coral reefs for food and livelihood. In the Philippines, more than 1 million small-scale fishers depend directly on coral reefs for their livelihood. The productivity of the fisheries sector (shrimp, lobster, conch and other high-valued species) in Belize, Honduras and Mexico is directly dependent on the health of the adjacent barrier reef, the longest in the hemisphere. Sustainable annual catches of fish from reefs vary from 0.2 to 30 tonnes/km^2, with an average of 5 tonnes/km^2 (Jennings and Polunin,1995). Depending on the value of the fish, reef fisheries are thus potentially worth US$15 000-150 000/km^2 a year, based on catch values of US$1-10 per kg (Talbot and Wilkinson, 2001). Reef fisheries in South-East Asia generate some US$2.4 billion a year (Burke et al., 2002), and in the Caribbean US$310 million a year (Burke and Maidens, 2004).

There is now a global market for reef species. Commercial reef fisheries are a major source of employment and foreign exchange, supplying export markets and retailers around the world, as well as the restaurant and hotel industries. The live reef fish trade supplies restaurants throughout South-East Asia with products from the Pacific and Indian Oceans (Hughes et al., 2003). Tuna fisheries, such as those in the Maldives and Lakshadweep, are often supported by reef-based bait fisheries, and tuna themselves depend in part on reefs for their food (Whittingham et al., 2003). Reef-based recreational fisheries generate over US$100 million annually (Cesar et al., 2003).

A large proportion of fish and invertebrates in the aquarium trade comes from coral reefs, shipped to the 1.5-2 million people in Europe and North America who have aquaria. Sri Lanka, for example, earns about US$5.6 million a year exporting reef fish to about 52 countries, an activity that supports directly and indirectly around 50 000 people. Large quantities of corals, shells, starfish, pufferfish and other species are used in the curio trade. Reef-based

S Wells

Some estimates suggest that reefs contribute up to 25 per cent of the annual total fish catch in developing countries, providing food for 1 billion people (Cesar et al., 2003).

P Scott

The high-value, low-volume nature of the aquarium trade means that it could provide a livelihood for many people if carefully managed: a kilo of aquarium fish was worth nearly US$500 in 2002, compared with a kilo of food fish which sold for about US$6 (Wabnitz et al., 2003).

curios provide significant export revenue, but the souvenir trade is largely unregulated and the benefits from it may be short term.

Mangroves are important as breeding and nursery areas for fish and prawns that form the basis of major fisheries (Bann, 1997; Sasekumar et al., 1992). Annual commercial fish harvests from mangroves have been valued at from US$6 200 per km^2 in the United States to US$60 000 per km^2 in Indonesia (Bann, 1997). An estimated 75 per cent of the commercially caught prawns and fish in Queensland, Australia, depend on mangroves for part of their lives and on nutrients exported from the mangroves to other ecosystems (Horst, 1998). The annual market value of seafood from mangroves has been put at US$7 500-167 500/km^2 (Millennium Ecosystem Assessment, 2005). With fish catches averaging 1.3-8.8 kg an hour, a 400-km^2 managed mangrove forest in Matang, west Malaysia, supports a fishery worth US$100 million a year (US$250 000/km^2/year). Many commercial shrimp fisheries are dependent on mangrove-fringed coastlines and estuaries including those in Central America and East Africa. In the Gulf of Panama, the fisheries for shrimps and fish generate an estimated US$95 000 per kilometre of coastline (Talbot and Wilkinson, 2001).

Mangrove forest products

Several mangrove species provide high-quality commercial timber, used for building and for making newsprint, matchsticks and matchboxes. Mangroves are also used in large quantities locally for house, boat and jetty construction. Mangrove timber is particularly valuable for construction as it is resistant to rot and to the boring activities of many marine invertebrates. Wood from several mangrove species has a high calorific value and is thus of value both directly as fuelwood and as charcoal. Mangrove wood was used as fuel in many of the early train engines in India, and it is still widely used in kilns to make lime (often using live corals from adjacent reefs). The Matang mangroves in Malaysia provide forestry products (timber and charcoal) with a value of US$30 000/km^2/year, and totalling US$10 million a year (Talbot and Wilkinson, 2001).

Mangroves provide a variety of traditional products. Tannins from mangroves were used to coat and preserve wood, nets and other fishing gear, as well as being used as a dye for cloth. In several countries, mangrove leaves provide fodder for cattle and goats. Mangrove forests have long been an important source of honey and beeswax. *Avicennia germinans* in Florida in the United States is particularly valued, as the bees that use this species make high-quality honey, and large quantities were produced until the late 1800s when progressive loss of the best forests led to a decline in production. Honey has been gathered from mangroves on a subsistence basis in numerous countries, and, with a renewed interest in this product, the activity is being developed on a small-scale commercial basis in many places (Horst, 1998).

Pharmaceuticals

Marine organisms often contain pharmaceutically active compounds, many of the source species coming from reefs. Reef organisms have provided an HIV treatment and a painkiller, while a large part of current cancer drug research focuses on coral reef species (Millennium Ecosystem Assessment, 2005). A study in Indonesia estimated that mangroves provide a potential net benefit of US$1 500 per km^2 (US$15/hectare) for medicinal plants (Ruitenbeek, 1992).

SUPPORTING SERVICES

The waters around mangroves are generally rich in nutrients, as a result of the organic matter produced by the trees and plants themselves, and also from the sediment that is trapped around the roots. Mangroves produce about 1 kg litter/m^2 annually, which forms the basis of a complex food chain and some of which is exported with the tide. As a result mangroves support an abundant and productive marine life, and often act as spawning areas, as well as nursery areas, sheltering juveniles of species that spend their adult lives in other ecosystems such as coral reefs and seagrass beds (Mumby et al., 2004).

What happens when ecosystem services are lost?

SECA/CML

Just as it is hard to calculate accurately the economic value of different ecosystems, it is equally difficult to predict the cost to society of losing their various services. It was thought that the bleaching event of 1998 in the Indian Ocean would have a major impact on tourism and fisheries. It was estimated, for example, that Tanzania would potentially suffer a direct loss of US$20 million from tourism revenue (Westmacott et al., 2000a). However, neither sector underwent the expected decline: tourism fluctuated but probably more as a result of worldwide political and economic changes; while fisheries are still in decline largely because of overexploitation.

Both the 1997 bleaching and the 2004 tsunami were single, if acute, events, and reefs and mangroves are expected to recover from damage incurred. A more typical scenario is of reefs and mangroves undergoing steady decline. Ecosystems that can no longer provide their full ecological services have a social and economic 'cost' to humanity, which can be felt in areas or situations many miles away. Ultimately, therefore, degradation of coral reefs and mangroves will cause loss of fishing and tourism revenue and other forms of livelihood, loss of export earnings, malnutrition due to lack of protein, increased coastal erosion, and destruction from storms and catastrophic natural events.

It is predicted that, for example, over a 20-year period, blast fishing, overfishing and sedimentation in Indonesia and the Philippines could lead to a net economic loss of US$2.6 billion and US$2.5 billion respectively for these two countries (Burke et al., 2002). In the Caribbean, coral reef degradation continuing through to 2050 could reduce benefits from fisheries, dive tourism and shore protection by a predicted total of US$350 million to US$870 million over that period (Burke and Maidens, 2004).

LOSS OF REGULATING SERVICES

The impact of the loss of the protective functions of coral reefs and mangroves is already being felt in some countries. Parts of Sri Lanka, India, Indonesia and the Maldives, where coral mining and collection has almost eliminated some reefs, have already seen serious erosion.

In Sri Lanka, erosion on the south and west coasts now averages an estimated 40 cm a year, considered to be partly due to damage to reefs. Some US$30 million has already been spent on breakwaters and other constructions to curtail this, and it has been estimated that the cost of replacing the coastal protection provided by these reefs would be US$246 000-836 000 per km (Berg et al., 1998). A hotel in West Lombok, Indonesia, spent an average of US$125 000 a year over a seven-year period restoring its 250-metre-long beach, which had been eroded largely because of offshore coral mining (Riopelle, 1995).

Modelling and predictions of the impact of the loss of natural shore protection provide dire warnings. Modelling of the changes in wave energy striking some island shorelines in the Seychelles (Sheppard et al., 2005) indicates that wave energy has recently doubled as a result of sea level rise, loss of corals from reef flats due to bleaching, and changes in reef crest profiles and wave

S Westmacott

In the Maldives, a reef flat adjacent to the capital of Male was filled using coral rubble and causing sedimentation of nearby reefs. Their degradation was partly responsible for reduced shore protection and extensive flooding in 1987, which resulted in 20-30 per cent of the new infill being lost. Subsequently, artificial breakwaters of concrete tetrapods were installed at a cost of US$10 000 per metre (or US$10 million per kilometre) (Brown, 1997). Not only was this expensive, but it did not prevent serious flooding during the tsunami.

regime. The models predict that, over the next decade, it will double again as a result of further damage to coral reefs. The consequences of this will depend on the shore's composition, but there will almost certainly be increased erosion on sandy shores.

In the Caribbean, more than 15 000 km of shoreline could experience a 10-20 per cent reduction in protection from waves and storms by 2050 as a result of coral reef degradation (Burke and Maidens, 2004). The economic costs to Australia from a degraded Great Barrier Reef as a result of the predicted impact of global warming have been put at US$2.5 billion to US$6 billion over 19 years (Hoegh-Guldberg and Hoegh-Guldberg, 2004).

Loss of mangroves causes saltwater intrusion and deterioration of groundwater quality, as well as the disappearance of the filtering mechanism provided by the roots and the ecological characteristics of this ecosystem.

Mangroves play a sufficiently important role in the global carbon cycle that it has been estimated that the loss of 35 per cent of the world's mangroves (Valiela, 2001) over the last two decades has resulted in the release of large quantities of stored carbon, thus further contributing to the greenhouse effect (Cebrian, 2002).

LOSS OF PROVISIONING SERVICES

The degradation of reefs and mangroves is already having a major impact on the livelihoods of thousands of coastal communities in the tropics, through loss of earnings and food security. Both overexploitation and habitat deterioration (particularly of nursery areas which causes disruptions to marine productivity) are leading to reduced catches in most tropical regions. For the Caribbean, it is predicted that, in the absence of reef degradation, fisheries production in 2015 could be 100 000 tonnes, with a revenue of US$310 million. However, with the reef degradation that is projected to occur, production may be 30-45 per cent less (60 000-70 000 tonnes), and revenue only US$140 million (Burke and Maidens, 2004).

LOSS OF CULTURAL SERVICES

Scuba divers specifically look for coral reefs with rich live coral, high fish and invertebrate diversity and clear water. In the long term, degradation of reefs will reduce their value to the tourist industry. Reefs will provide less interesting diving and snorkelling, poorer sport fishing and, where erosion has taken hold, less attractive beaches. For the Caribbean, it is predicted that, if reefs undergo no further deterioration, net benefits from scuba diving could grow to US$5.7 billion by 2015. If reef health deteriorates further, however, dive revenue could amount to only US$5.4-5.6 billion, representing a future 'loss' of 2-5 per cent (Burke and Maidens, 2004). Already it is widely believed in Florida, United States (although data are lacking) that the decline in reef quality is partly responsible for the shift from high-value, low-volume tourism to budget travellers; this reduces revenue and potentially, if large numbers are involved, further contributes to the degradation of the reefs (T. Agardy, pers. comm.).

R A Patzner/University of Salzburg

The commercially important rainbow parrotfish Scarus guacamaia *in the Caribbean depends on mangroves as a juvenile but lives on reefs as an adult. It is far less common on reefs with no adjacent mangroves, and is one of probably many species that are declining from loss of habitat as well as overfishing (Mumby, et al., 2004). Local extinctions have been reported where mangroves have been cleared, as at Glover's Atoll in Belize (A. Edwards, pers. comm.).*

Natural recovery – or rehabilitation and restoration

UNEP/Topham

Mangrove restoration.

Although our instinct is to repair or restore something that has been damaged, there is often an argument for allowing natural recovery. There are, indeed, many examples of reefs and mangroves recovering from a major impact such as a hurricane without human intervention. Although recovery may seem slow, natural regeneration increases the likelihood that the ecosystem will return to what it was before.

The many chronic, long-term impacts now affecting these ecosystems often slow the rate of recovery. On reefs, for example, the shift from a coral-dominated to an algal-dominated ecosystem means that new coral recruits are quickly outnumbered and those that settle often have little chance of survival. The focus now needs to be on removing the causes of this imbalance, and eliminating stresses in order to encourage natural recovery of damaged ecosystems (Edwards and Clark, 1998; Cahoon and Hensel, 2002).

However, there may be certain situations or conditions when active intervention is necessary or beneficial, for example where an ecosystem has particularly high economic value or scientific interest. There are two terms in common use: 'restoration', which means that all the key ecological processes and functions and all the former biodiversity are re-established; and 'rehabilitation' which means that most, but not all, are re-established. Most experience so far with reefs and mangroves is in terms of rehabilitation.

Mangrove rehabilitation can be relatively simple since comparatively few species are involved. However, rehabilitation of reefs is more complex because coral reproductive biology and growth rates are still poorly understood, many species are involved and the techniques are complex and expensive, requiring scuba-diving and other special equipment and materials. Reef rehabilitation projects have so far been largely experimental and have involved only small areas (less than 100 m^2). A careful evaluation of the methods available must be undertaken to determine feasibility and cost effectiveness before any attempt at rehabilitation is made. Research into coral reef restoration is currently under way through the GEF/World Bank Coral Reef

Targeted Research and Capacity Building for Management project (Edwards, 2004).

Reefs and mangroves comprise different combinations of species and occur in a variety of physical conditions and locations. These factors, combined with the type and scale of damage suffered, will affect recovery processes and thus any decisions about rehabilitation.

CORAL REEFS

Reefs will generally recover provided there is an adequate supply of larvae of corals, fish and invertebrates, and as long as chronic disturbances such as sediment, pollution and overfishing are minimized. Recovery involves two processes: the settlement of larvae which then develop into new coral colonies; and growth of the remaining coral colonies and fragments. Both processes are affected by the prevailing environmental conditions and by the extent of the damage. New coral growth and recolonization of fish populations will start to occur within one to two years of a damaging event or the end of damaging activities.

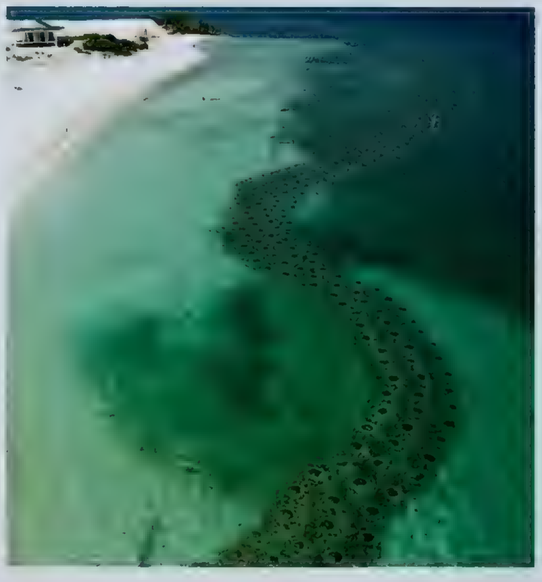
Coral larvae require hard surfaces, preferably coral rock or coralline algae, for settlement, and so seaweeds, sediment and debris on the seabed will reduce coral recruitment. However, coral spawning can take place quite normally after a natural event such as a hurricane. For example, in Guam, after a typhoon, coral spawning took place at the normal time and even broken coral fragments were seen to spawn.

Coral growth rates are highly variable, depending on the species, the location of the colony on the reef, the geographical location of the reef and environmental conditions. Branching corals grow relatively fast (10-20 cm a year) but are easily broken by waves and storms. Massive corals grow very slowly (5-25 mm a year) but may survive for hundreds of years; colonies more than 1 000 years old have been found. The reef as a whole grows more slowly than its individual corals, as it is constantly being eroded, and upward growth on reef flats is only about 4 mm a year, while deeper reef thickets grow at about 10 mm a year. The breakdown of coral skeletons results from either mechanical damage or from 'bio-eroders', which include sea urchins that graze on fine algae on the surface of corals and abrade them in the process, and sponges that bore into corals and weaken their structure.

The speed of a reef's recovery from major damage thus depends on the balance between the growth of coral colonies and their erosion. Recovery time is generally a matter of decades (10-50 years) and is longer on reefs subject to other long-term stresses, although the process of recovery can start in as little as two years. Natural recovery of mined reefs in the Maldives has been particularly slow (Clark and Edwards, 1994). Reefs in marine parks in eastern Indonesia, which had previously suffered from long-term dynamite fishing, show little sign of recovery after seven years, despite good water quality and larval recruitment. The vast quantities of broken rubble act as 'killing fields' for juvenile corals, abrading or burying the newly settled recruits (Fox et al., 2003). Reefs that suffered light damage from the 2004 tsunami in Thailand are predicted to take only three to five years to recover; those that received greater damage may take five to ten years. However, the rates of recovery will depend on whether the reefs suffer other impacts in the coming years, particularly bleaching which has occurred several times in Thailand in the past (Phongsuwan and Brown, in press).

The main approaches to rehabilitation of coral reefs are (Westmacott et al., 2000b):

- Increasing the area of substrate for settlement of coral larvae by installing artificial surfaces, e.g. concrete blocks, wrecks or other purpose-designed structures. Stabilizing or removing



www.reefball.org

A major industry has developed in recent years to build artificial reefs, such as this 'Reefballs' breakwater, to replace the original natural reefs and create new amenity value. Although the costs of such structures are decreasing, this approach is expensive, and not feasible for large areas; most importantly, an artificial structure such as this will never replace all the ecosystem services of a natural reef. Before investing in potentially risky 'engineering' solutions to reef restoration, it is essential to seek advice from scientists and other experts.

J Harris

Reef restoration projects are under way in many areas, as here in the Solomon Islands. The tsunami gave fresh impetus to such projects but they will need careful assessment. Experience to date suggests they are appropriate only at the scale of tens to at most hundreds of square metres, for example on reefs damaged by shipping or used by tourists.

loose or soft substrate, such as coral fragments and seaweeds, can also help, but this procedure requires care and expert help. New surfaces can be created by passing an electric current through metal to cause deposition of calcium carbonate (electrolysis). This requires considerable financial and human investment, and the long-term impact of the current in the water is not known.

- Transplanting coral fragments or colonies from healthy reefs to damaged reefs or to artificial substrates. Many species survive transplantation provided environmental factors are favourable, but the process requires significant labour, and transplanted fragments are easily dislodged by waves and human disturbance, or can easily be buried or smothered. In addition, there is a risk of damaging healthy reefs by removing corals from them. Coral fragments can also be transplanted to a protected site and 'grown out' (or 'farmed') to a certain size before being used for rehabilitation (Epstein et al., 2003).
- 'Repairing' the reef: Under some circumstances, it is possible to cement pieces of reef, or even coral colonies, together, using glue, special cements, plastic or other binding agents.

MANGROVES

Mangrove regeneration is affected by the patterns of damage (e.g. broken branches, impact from debris, sediment disturbance) and by the characteristics of the area. After storms and impacts such as a tsunami, sediment scouring leaves inorganic substrates that are difficult for mangroves to colonize. Sediment turnover may also expose and/or dump onto existing mangroves material in which there has been long-term accumulation of heavy metals, hydrocarbons and other contaminants that inhibit seedling establishment and survival (Ellison and Farnsworth, 1996; Cahoon and Hensel, 2002). As with reefs, for effective recovery it is essential that the causes of the damage are eliminated. Even when disturbance is reduced, the altered soil conditions (e.g. increased acidity where aquaculture was previously carried out) and limited natural dispersal of many mangrove species mean that natural recovery can be very slow.

Most mangrove species produce propagules that are relatively easy to collect and plant and, in the right conditions, growth is fast. Restoration projects usually involve the direct planting of propagules (particularly for *Rhizophora* spp.) in the recovery area, although seedlings and saplings can be grown up in advance in nurseries. The exact technique to be used will depend on the species involved, whether the soil needs treatment (for example to reduce acidity) or physical reworking (to create a suitable grain size), the season, the developmental stage of the propagules and the resources available. Replanting is generally most successful in relatively sheltered areas, but is also carried out in more exposed areas where the main aim is control of soil erosion (Stevenson, 1997).

Partly because of the ease with which propagules can be replanted, many mangrove restoration schemes have been undertaken, often as a forestry production initiative. Replanting schemes in Matang, Malaysia (Chan, 1996), Thailand (Fast and Menasveta, 2003) and East Africa (Kairo et al., 2001) have been successful, although rehabilitated mangroves often lack their full biodiversity and ecological processes (Ellison, 2000). Many of the Asian countries affected by the 2004 tsunami have embarked on ambitious replanting programmes which are nevertheless a first step. Indonesia, for example, has initiated a four-year operation to plant 150 000 hectares of mangroves along the coast of Aceh where 300 000 hectares of mangroves were destroyed. Such programmes will require careful monitoring and assessment if full restoration is to be achieved. There is some evidence that greater success in recovering the biodiversity is achieved when the replanting is carried out in association with integrated aquaculture systems (Ellison, 2000).

Mangoves and coral reefs on tropical coastlines of the future

Devastating as they were, the tsunami of December 2004 and recent tropical storms have sent a clear message that investing in environmentally sound development and sustainable management of the coastal environment will, in the long run, be more cost effective than restoring human lives and ecosystems after a catastrophe. Tsunamis are relatively rare events compared with hurricanes and cyclones – fewer than 100 tsunamis were recorded over the last 300 years in the Indian Ocean (Dahdouh-Guebas et al., 2005; Department of Ocean Development, 2005) compared with three tropical cyclones a year (Dahdouh-Guebas et al, 2005). Evidence for the shore protection benefits of coral reefs and mangroves is currently less for tsunamis than it is for storms. This, however, does not lessen the urgency – the devastation recently wrought by hurricanes and typhoons testifies to the priority that must be accorded to shore protection measures, of which maintenance of natural coastal barriers such as reefs and mangroves must be among the first.

There are no simple management models for mangroves or reefs. The variability of these ecosystems means that a good understanding of local characteristics is essential. In the case of mangroves, even though a common feature is their regular inundation by the sea, the extent of this inundation and the tidal regime vary greatly as do their species composition and the chemical and microbial characteristics of the soils, all of which affect their resilience and ability to recover.

MAINTAINING REGULATING SERVICES

Human activities that weaken reefs and make them less effective breakwaters must be regulated or halted as a matter of urgency, and alternative livelihoods found for those dependent on the activities that cause damage. Good coastal planning can considerably reduce vulnerability to natural disasters, as well as help safeguard other regulatory services such as water quality maintenance. Full implementation of the UNEP Global Programme of Action on Land-based Sources of Pollution will go a long way towards helping to maintain the regulating services of reefs and mangroves.

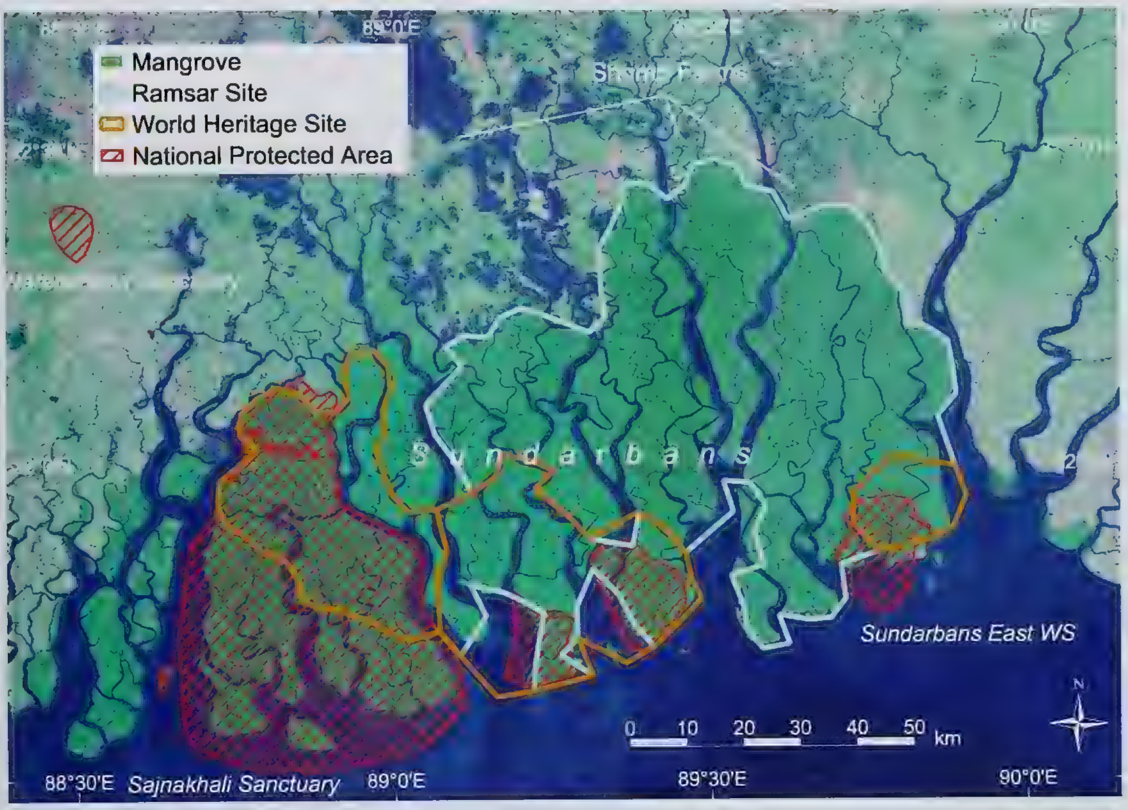
MAINTAINING PROVISIONING SERVICES

The sustainable exploitation of reef and mangrove fisheries and other resources is a recognized global priority. There are some success stories, such as the harvesting of mangrove timber over a 20-30 year rotation period in Bangladesh, Malaysia and Thailand. Much greater attention must, however, be paid to fisheries management. Techniques and approaches are well developed but often poorly implemented. The FAO Code of Conduct for Responsible Fisheries enshrines many of these, including elimination of destructive fishing gear, establishing no-take areas, and emphasizing the need for management plans, developed with the full involvement of fishers and users, that are fully enforced. In Sri Lanka, where 80-95 per cent of the fishing fleet was destroyed in areas affected by the 2004 tsunami, there was an opportunity to introduce measures, such as reduction of overcapacity, to ensure sustainability. However, in the rush to provide humanitarian aid, fishing gear and boats have been distributed in large numbers and without consideration of the long-term future. This demonstrates the need for a much greater understanding by the public and decision makers of the management requirements of nearshore tropical fisheries.

Cancún Travel Online

Thirty years ago, Cancún in Mexico, lying at the top of the great Meso-American Reef System, was a small fishing village. Since then, it has grown to a resort that receives more than 3.5 million visitors annually, on top of its 650 000 residents, and has suffered considerable environmental problems, particularly in the form of numerous hurricanes, such as Ivan in 2004 (left) and Emily and Wilma in 2005. In 2001, Guidelines for Low-Impact Tourism *were produced for the state of Quintana Roo (Molina et al., 2001). These aim to ensure that further tourism development, particularly in the Costa Maya to the south of Cancún, will avoid many of the existing problems, and will contribute to the sustainable development of this region without increasing its vulnerability.*

UNEP



The Sundarbans, lying at the southern end of the Ganges River and straddling the border between India and Bangladesh, is the largest continuous area of mangrove in the world. The area provides a livelihood for more than 300 000 people, protects them from cyclones and tidal waves and is an important source of revenue for both countries through commercial timber which is harvested on a 20-year felling cycle. The total extent – some 6 050 km² (Spalding et al., 1997) – has not changed significantly in the last 25 years, although there are concerns that forest quality may be declining. The relative success of the Sundarbans is largely due to its management which has been aimed at taking advantage of the mangroves' provisioning and regulatory ecosystem services. It has been managed as a commercially exploited reserved forest since 1875; wildlife sanctuaries and national parks protect key biodiversity areas, and the area is both a World Heritage and a Ramsar site. Since the 1970s, the Sundarbans has also been managed as a protective belt against storm damage.

MAINTAINING CULTURAL SERVICES

The vulnerability of the tourism industry to natural events was made very clear by recent hurricanes as well as the 2004 tsunami. Maintaining the ecosystems on which the industry depends is thus of paramount importance to both governments and the private sector. The International Ecotourism Society (Halfpenny, 2002), the Convention on Biological Diversity (CBD, 2004), the Center for Environmental Leadership in Business (CELB/CORAL/ IHEI/TOI, 2004) and others have produced guidelines to promote sustainable tourism. Political will and individual commitment are now needed to ensure their implementation.

Although many coastal communities have traditionally valued the ecosystems on which they depend, much of this understanding has been eroded. The growing recognition of the role of communities in the stewardship of natural resources, and the numerous examples of how this can be successful, will help to ensure that the cultural services of reefs and mangroves continue to be valued.

ESSENTIAL MANAGEMENT TOOLS

There is no shortage of guidelines, codes of practice and information on how to manage reefs and mangroves but there is there is still a notable lack of commitment to using and implementing them. The UNEP Regional Seas Programme is among the organizations trying to reverse this, by helping countries to work together to protect these ecosystems, recognizing that success involves transboundary action, regional co-operation and clear demonstration of successful approaches (see for example UNEP 2004). Key management approaches that must be

promoted include integrated coastal management (ICM), marine protected areas (MPAs), and improved resilience and adaptive management.

Integrated coastal management

Coastal development is often *ad hoc* and based on numerous unconnected small decisions, or, where plans exist, may be illegal as a result of poor enforcement of regulations (Kay and Alder, 2005). National and local ICM programmes can go a long way to improving coastal management. The links between impacts on the coast and watershed management need to be recognized. Plans should take into account soils, topography and the need to protect vulnerable ecosystems. Areas needing rehabilitation must be identified, as well as areas where construction should be restricted or banned.

In particular, the construction industry must respect environmental principles (such as set-back regulations), and ensure that pollution and sedimentation are minimized through measures such as the use of silt curtains, and building in the dry rather than the wet season. Incorporating knowledge of coastal processes and applying best management practices for beaches, lagoons, coastal vegetation, energy, sewage treatment, solid waste and wastewater into planning and infrastructure are essential. Construction behind reefs will need particular care, not only to prevent damage to these ecosystems, but to reduce future shoreline damage if channels through the reef do indeed increase vulnerability to flooding. Environmental impact assessment legislation, now in place in most countries, must be enforced as a matter of urgency.

The ICM approach is fully recognized in the 12 guiding principles that were drawn up at a meeting in Cairo in February 2005 by the UNEP Asian Tsunami Disaster Task Force, in collaboration with the UNEP Co-ordination Office of the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities and other organizations (UK Department for Environment, Food and Rural Affairs, the Food and Agriculture Organization of the United Nations, the United Nations Educational, Scientific and Cultural Organization, IUCN, and WWF). Known as the Cairo Principles, these are aimed at helping to ensure environmentally sound post-tsunami reconstruction programmes, and are being implemented through an Action Plan (UNEP/GPA, 2005).

THE CAIRO PRINCIPLES

Overarching principle

1 Reduce the vulnerability of coastal communities to natural hazards by establishing a regional early warning system and applying construction set-backs, green belts and other no-build areas.

Priority technical measures

2 Promote early resettlement with provision for all basic livelihood needs.

3 Enhance the ability of natural ecosystems to provide protection by conserving, managing and restoring wetlands, mangroves, seagrass beds, and coral reefs, and by seeking alternative sustainable sources of building materials.

4 Promote design that is cost-effective and consistent with best practices, favouring soft engineering solutions to coastal erosion control.

5 Respect traditional access and uses of the shoreline.

6 Adopt ecosystem-based management measures; promote sustainable fisheries management; encourage low-impact aquaculture.

7 Promote sustainable tourism.

How to apply the principles

8 Secure commitments from governments and international organizations to abide by the principles.

9 Ensure public participation.

10 Make full use of tools such as strategic environmental assessment, spatial planning and environmental impact assessment.

11 Monitor the progress and impact of reconstruction.

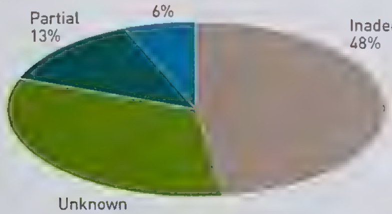
12 Disseminate good practices and lessons learnt as they emerge.

Marine protected areas

There is growing evidence that reefs within MPAs recover faster from catastrophes than those that are unprotected. The abundant fish populations in Hikkaduwa National Park, Sri Lanka, showed little change as a result of the 2004 tsunami, although unprotected reef sites appear to have suffered losses (*MPA News*, 2005). Reefs in the Indian Ocean that were well managed or remote from human impact tended to recover more rapidly from the 1998 bleaching; reefs under anthropogenic stress recovered poorly, if at all (Wilkinson, 2004).

Many more MPAs are needed. Currently, some 685 protected areas contain mangroves, covering about 9 per cent of the total area of mangrove (Spalding et al., 1997), and 660 MPAs contain coral reefs. There is no global estimate of how much reef is protected (Spalding et al., 2001), but in the Caribbean an estimated 20 per cent of reefs lie within MPAs (Burke and Maidens, 2004). Many MPAs need to be larger and to be made part of carefully designed networks to ensure that connected ecosystems

Fig. 5: **Management effectivenes of Caribbean MPAs** (per cent)



Most marine protected areas urgently need improved management. Of 285 MPAs assessed in the Caribbean in 2004, only 6 per cent were considered to be effectively managed (Burke and Maidens, 2004).

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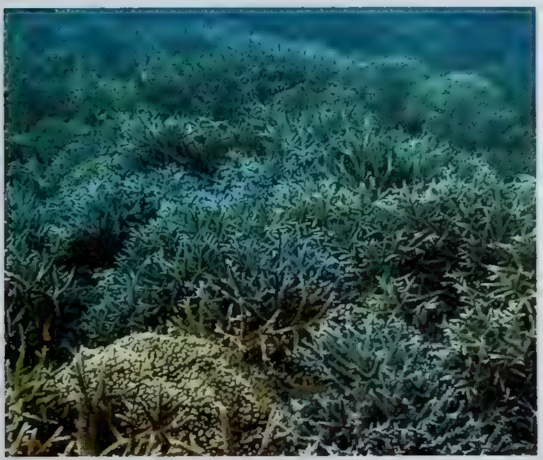


Mu Koh Surin National Park in Thailand, gazetted in 1981 and covering 135 km², is an ICRAN demonstration site and has a good track record of effective management. The December 2004 tsunami largely destroyed tourism and the park's infrastructure on the islands, as well as sea gypsy villages, but there were no fatalities. The coral reefs, which were especially healthy with high biodiversity before the event (see above), were being surveyed at the time of the tsunami, permitting first-hand accounts. Trees were knocked onto the reefs, along with large amounts of sediment. A survey was carried out two months later and remarkably little damage had occurred: reefs had an average of 75 per cent live coral cover, and some had 90 per cent, the sediment had gone, and there were already signs of some coral regeneration in damaged areas (Comley et al., 2005).

are protected (not only representative sites), as well as resilient ecosystems, such as reefs identified as resisting or recovering quickly from bleaching (Grimsditch and Salm, 2005). This is essential if species dependent on different ecosystems at different stages of their life cycles are to be protected, and the full range of ecosystem services maintained.

Improved resilience and adaptive management

Natural disasters have affected humans and the environment since the beginning of time – but both have the ability to regenerate and adapt to the impact of such events and the new circumstances that may arise as a result of them. This capacity to absorb recurrent disturbances such as storms and floods is called 'resilience'.

Already two-thirds of the coastal disasters recorded each year are associated with extreme weather events. The growing populations on, and rapid development of, the coastal zone guarantee that we will see an increase in economic, social and environmental damage in the future caused by the associated reduction in human and ecosystem resilience. The conventional approach has been to try to reduce the damage and eliminate change but a new thinking is developing. A far better approach may be to promote the conditions that improve resilience and also learn to adapt to the resulting changes (Adger et al., 2005). Careful planning and adaptive management can greatly reduce the impact of large disturbances.

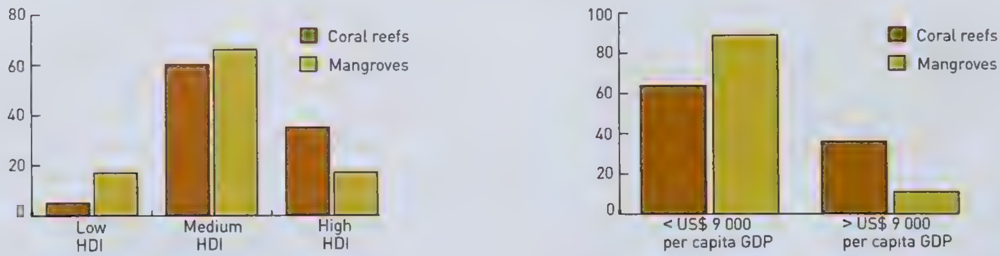
The rapid response of global, regional and national monitoring programmes to the tsunami demonstrated their value in providing essential information for management. *Guidelines for Rapid Assessment and Monitoring of Tsunami Damage to Coral Reefs* were produced within ten days (ICRI/ISRS, 2005) and disseminated by the UNEP Coral Reef Unit to the various international and UN agencies conducting environmental assessments in the region. Expert surveys were also quickly initiated with assistance from the Global Coral Reef Monitoring Network (GCRMN) and the regional Coral Reef Degradation in the Indian Ocean (CORDIO) programme.

FINANCING THE FUTURE

Reefs and mangroves clearly provide significant benefits and services to humankind, many of which have a high economic value. Governments, civil society and the private sector must recognize that, as with other benefits, there is a price to be paid for maintaining these ecosystems. The cost is, however, generally much lower than the benefit received.

Although costs are hugely variable depending on the location, size and type of management, average annual operational management costs of US$775 per km² have been estimated for MPAs (Balmford et al., 2004). This is significantly less that the estimated global values of ecosystems: US$100 000-600 000 per km² per year in the case of reefs and possibly more for mangroves. Basic annual operating costs for MPAs can be as low as

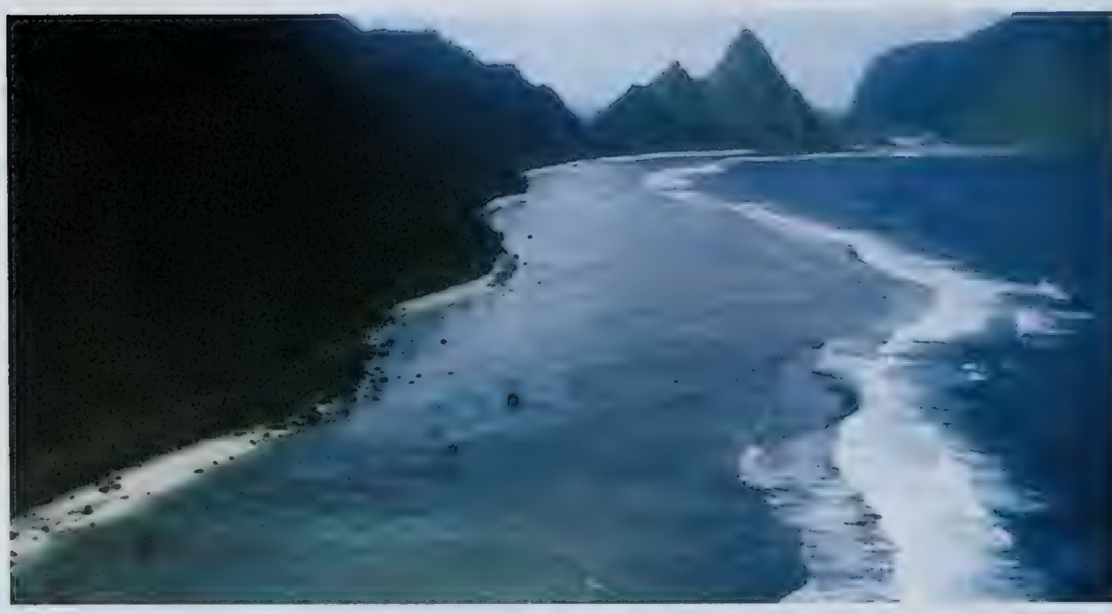
Fig. 6: **Area of the world's coral reefs and mangroves lying within the waters of countries in relation to those countries' position on the UN Human Development Index (left) and their GDP per capita (right)** (per cent)



Many of the world's wealthiest nations have jurisdiction over reefs and mangroves, either in their own coastal waters or in those of their territories. Over 30 per cent of the world's reefs lie in countries that are classified as highly developed, with a GDP per capita of more than US$9 000. Australia, France, New Zealand, the United Kingdom and the United States directly influence about 25 per cent of reefs and a significant proportion of mangroves. Furthermore, most of these countries are either sources of tourists to reef countries or have other strong economic links with them and potentially could provide much greater financial and technical support. A higher proportion of mangroves are found in the poorer countries, but nevertheless more than 10 per cent are found in highly developed countries.

US$200 000-600 000, as in the case of Belize and the Seychelles (Lutchman, 2005).

There are vast untapped sources of funds and financing mechanisms, ranging from fishery and tourism revenues and taxes, to royalties and fees from offshore mining and mineral exploitation, to voluntary donations and government aid (Spergel and Moye, 2004). Studies have indicated, for example, that tourists are willing to pay more than US$50 extra per holiday and divers US$25 more per dive if these result in high-quality reefs (Westmacott et al., 2000a; Burke and Maidens, 2004). It seems a small price to pay for the future survival of these small, priceless ecosystems.



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In the **front line**

Shoreline **protection** and other **ecosystem services** from **mangroves** and **coral reefs**

The tragic and devastating consequences of the Asian tsunami, December 2004, and the hurricanes and cyclones of 2005 were a wake up call for the global community, dramatically drawing attention to the dangers of undermining the services that coastal ecosystems provide to humankind.

This report has gathered lessons that have been learnt since these events that will be relevant to future management of the coasts in the context of severe weather events and other potential consequences of global warming. More than ever it is essential to consider the full value of ecosystem services – that is the benefits that people derive from ecosystems – when making decisions about coastal development.

The publication aims to help decision and policy makers around the world understand the importance of coastal habitats to humans, focusing on the role of coral reefs and mangroves. As well as coastal protection, it also addresses the huge range of other benefits provided by these ecosystems and the role that they can play in coastal development and in restoring livelihoods for those suffering from the effects of extreme events.

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